Anatomy of the Nervous System

Chapter 2

Content

2.1 Central nervous system (CNS)

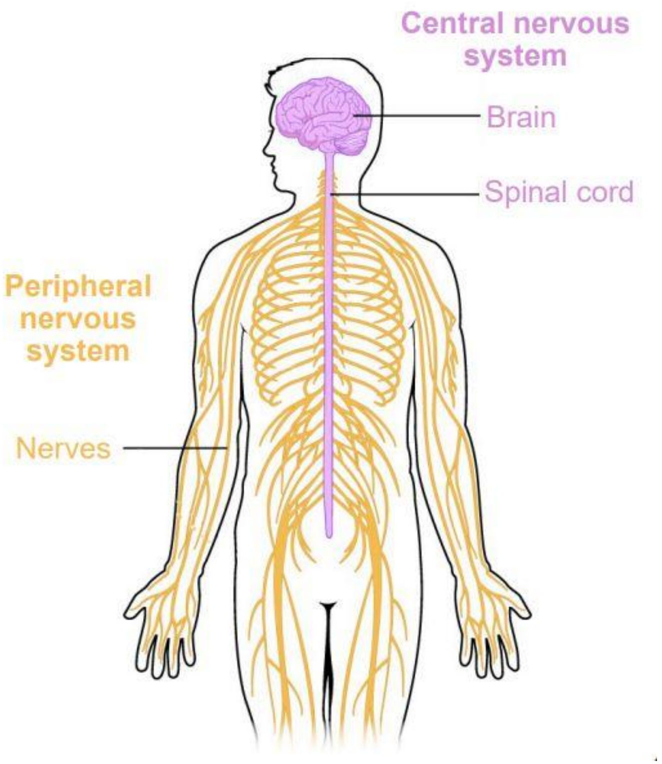
2.2 Peripheral nervous system (PNS)

2.3 Support structures of the nervous system

Division of the nervous system

- 2 main categories:
  - Central nervous system (CNS; includes brain & spinal cord)
  - Peripheral nervous system (PNS; nerves)

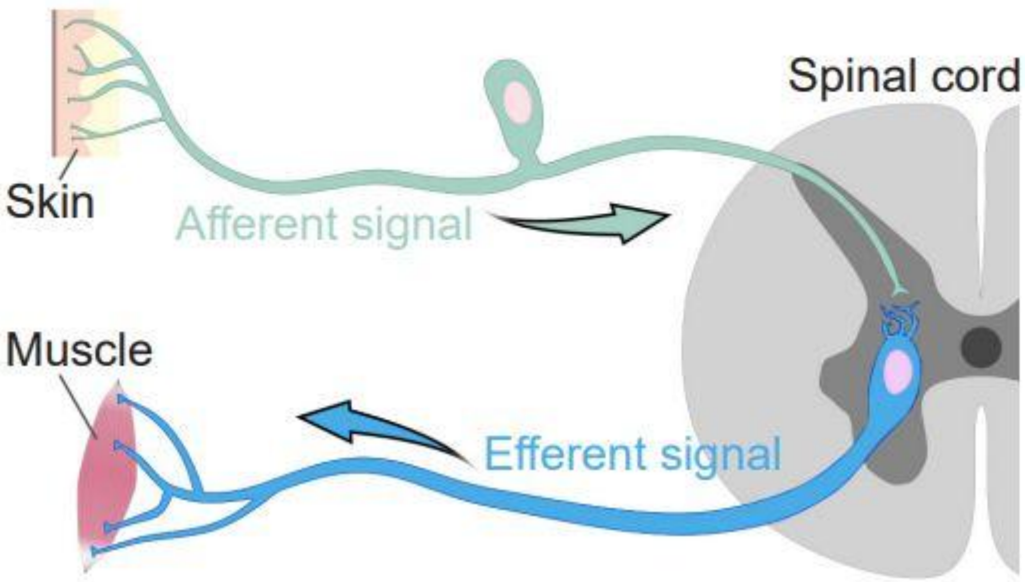
Figure 2.1 Anatomical structures of the CNS and the PNS.



Naming Signals

- Origin and direction of signal determine the labelling of the signal
  - Afferent (incoming; ascending; coming to the CNS)
  - Efferent (outgoing; descending; moving out of the CNS)

Figure 2.2 Afferent versus efferent signals.

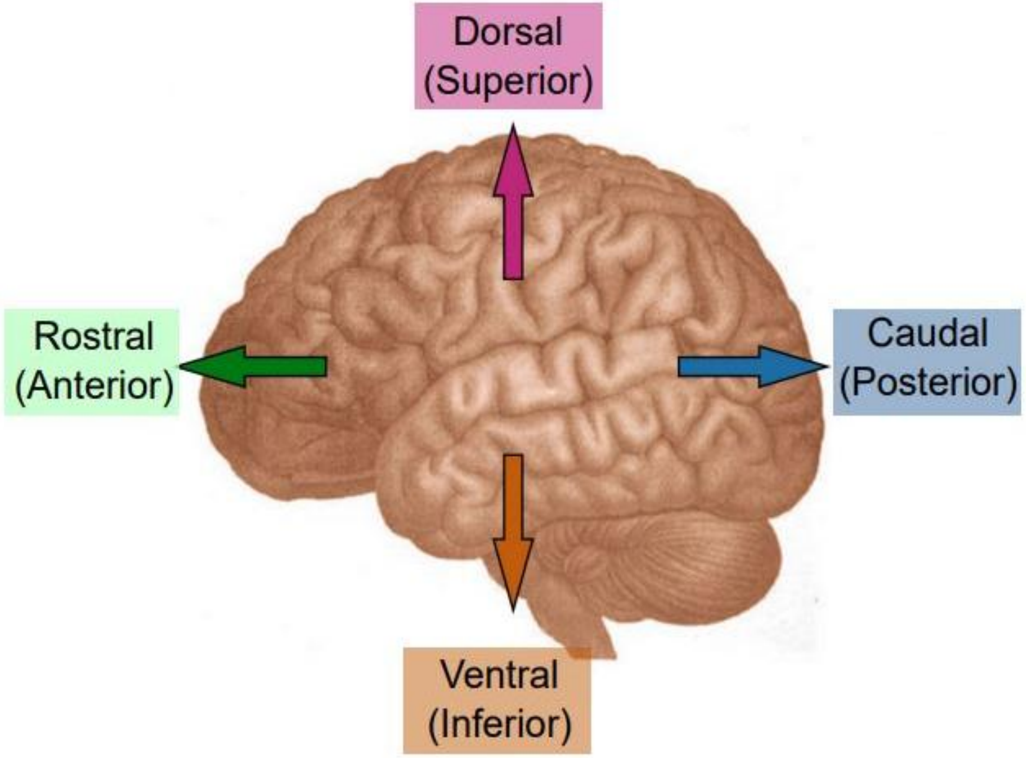


Central nervous system (CNS)

- As aforementioned, brain & spinal cord
- Brain
  - Size: 160 mm (16 cm; ~6 inches) in length x 90 mm (9 cm; ~3.5 inches) in height
  - Volume: 1400 cm^3; would fill about 1/3 of a gallon (barely 2% of body weight)
  - Small size
  - Uses 1/5 of body's energy expenditure (20% of body’s energy)

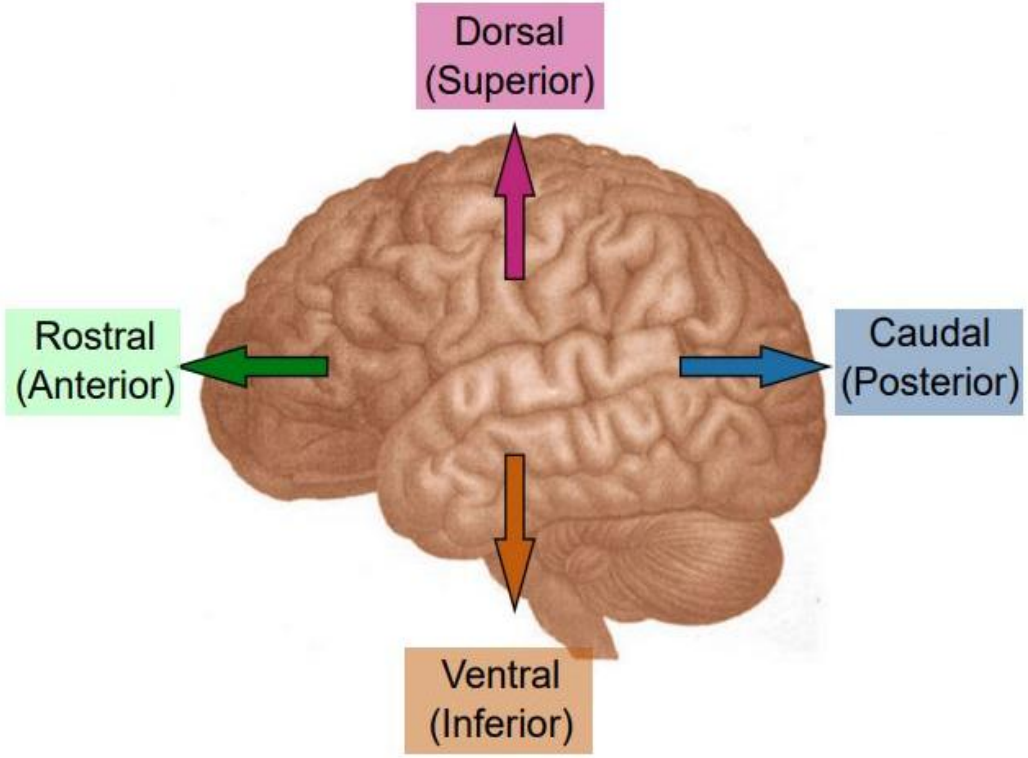
Anatomical Language of the Brain: front vs back

- Consider person facing sideways & desire to discuss "front of the head" and "back of the head"
  - More forward = rostral (*beak*) OR anterior (*before*)
  - More towards back part of brain = caudal (*tail*) OR posterior (*after*)



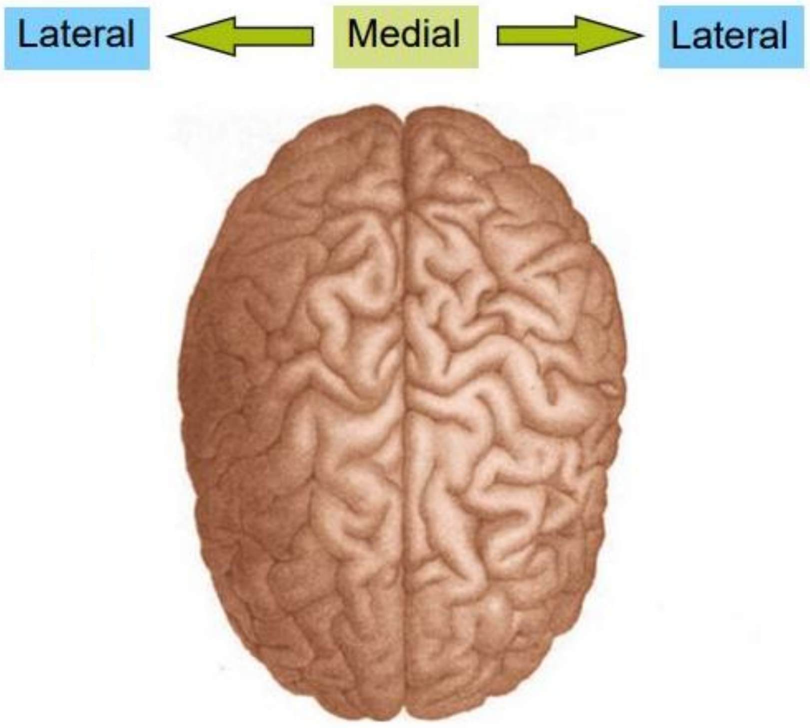
Anatomical Language of the Brain: top vs bottom

- Consider desire to discuss "top of the head" and "bottom of the head"
  - More towards top of head = dorsal (*back*) OR superior (*above*)
  - More towards back part of brain = ventral (*belly*) OR inferior (*below*)



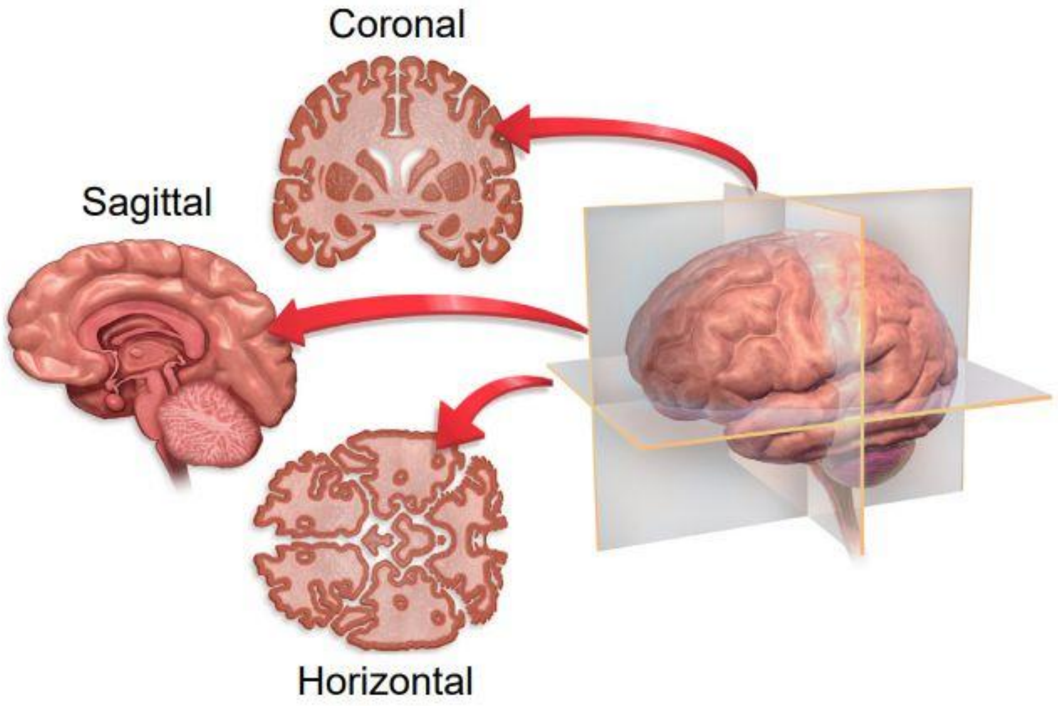
Anatomical Language of the Brain: towards vs away from center

- Consider person facing you & desire to discuss "closer to the center of the brain" and "closer to the sides of the brain"
  - Closer to center = medial
  - Closer to sides of brain = lateral



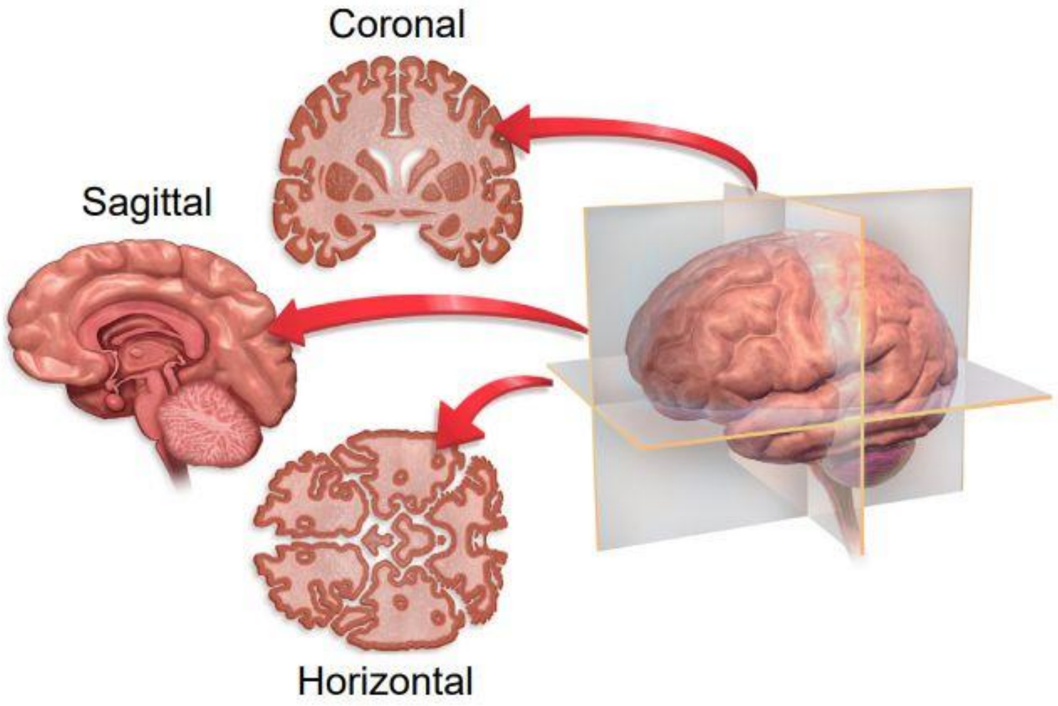
Dissection Orientation

- Consider person looking to left & brain
  divided into sections
  cut (or brain images taken) along vertical lines
- Coronal (from *corona*; Latin for *crown*)
- AKA frontal



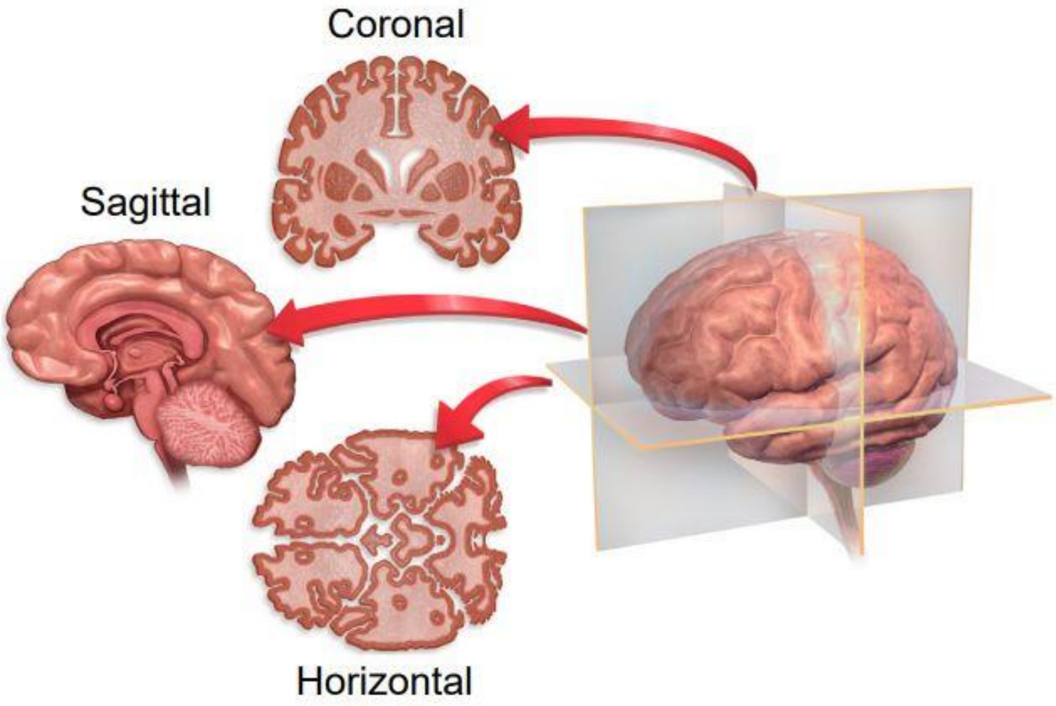
Dissection Orientation

- Consider person looking to left & brain divided into sections cut (or images are taken) along dorsal-ventral
- Horizontal (or axial, especially in humans; AKA transverse)



Dissection Orientation

- Consider person looking at you & brain divided into sections cut (or images are taken) from left to right (parallel to midline)
- Parasagittal
  - Never symmetrical
  - Sagittal (comes from Latin word for *arrow*)



Let’s look at these dissection orientations in another way

- Anatomical Planes

Sliced Sections of Brain

- White matter (myelinated)
  - Fatty lipid causes reflection of light – making it appear white
- Gray matter
  - Darker pink or gray in color
  - Dense with cell bodies
- Two similar halves
  - Left and right hemispheres
  - White matter tract allowing for communication between the two = corpus callosum

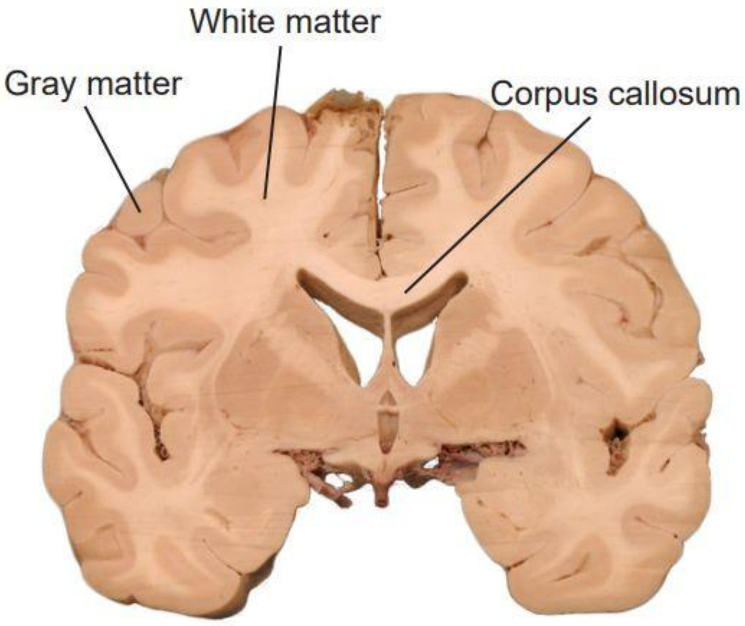


Figure 2.5 Coronal brain section showing examples of white matter, gray matter, and the **corpus callosum**, the major communication tract between the left and right hemispheres.

Brain Structures throughout Development

- 3 main germ layers of embryo:
  - Ectoderm
    - Fold into itself and merges at surface, creating the neural tube (3-4 weeks of gestation)
  - Mesoderm
  - Endoderm

2-Minute Neuroscience Video: Early Neural Development

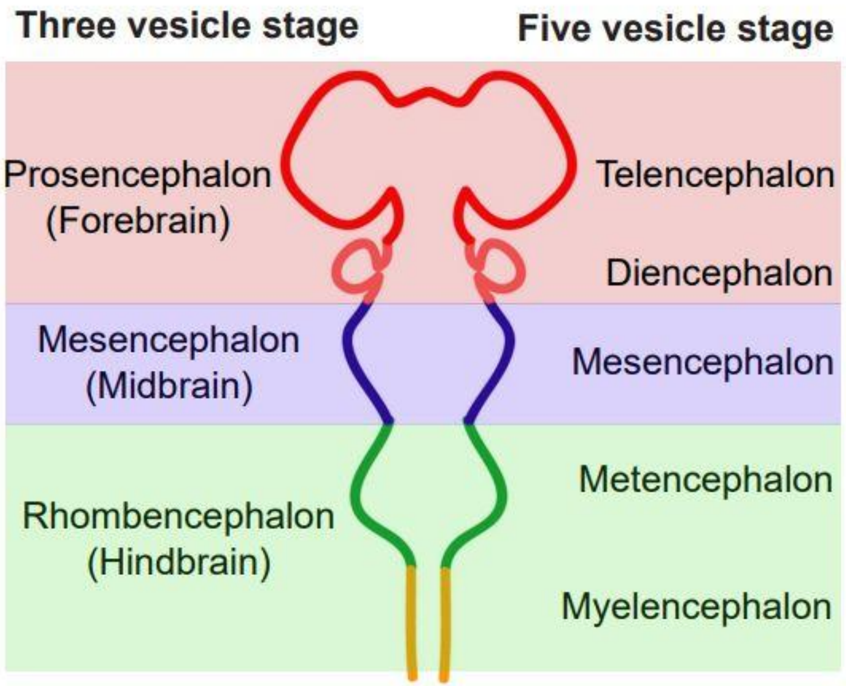
Brain Structures throughout Development

- Neural tube
  - Moves from "three-vesicle stage" to, one-week later, "five-vesicle stage"
  - Names of vesicles can describe the stages of development
    OR the grouping of structures that form in adulthood

Brain Structures throughout Development

- Vesicles from posterior to anterior
  - 1 Rhombencephalon (hindbrain)
  - 1 a) Myelencephalon
  - 1 b) Metencephalon
  - 2 Mesencephalon (midbrain)
  - 3 Prosencephalon (forebrain)
  - 3 a) Diencephalon
  - 3b) Telencephalon

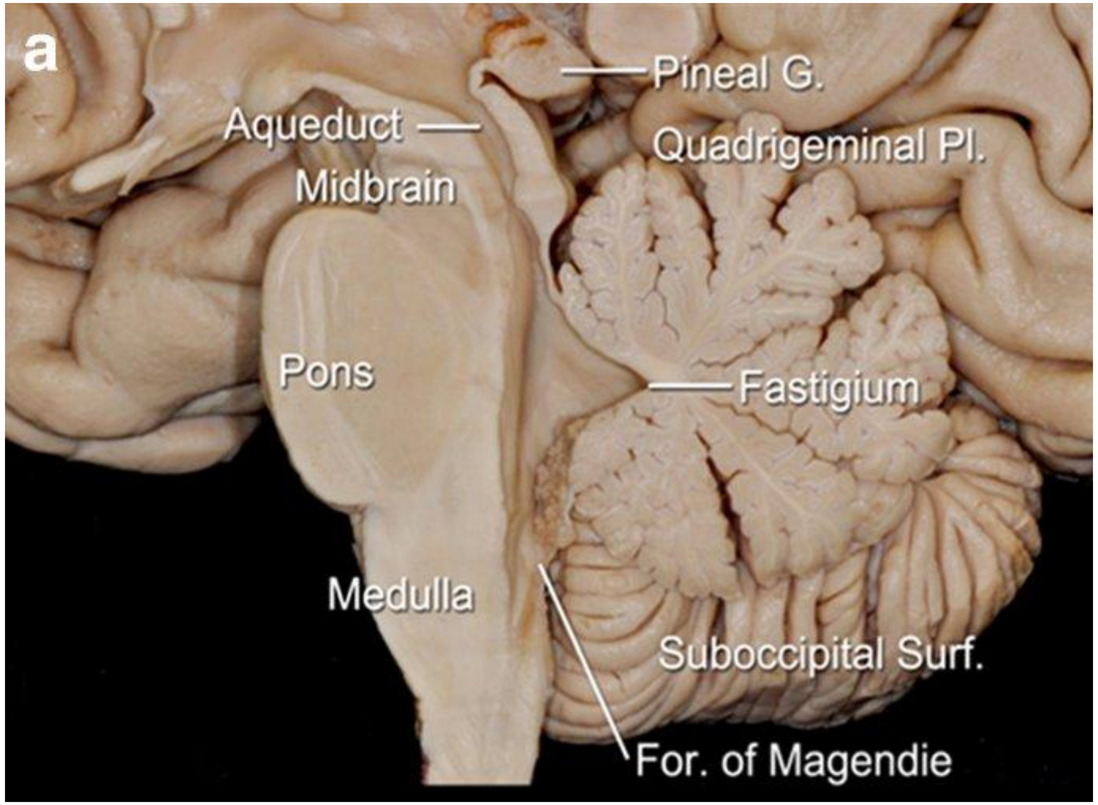
Figure 2.6 The future structures of the developing nervous system.



Brain Structures throughout Development

1. Rhombencephalon (hindbrain)
   - Evolutionarily, oldest part of CNS
   - Structures likely evolved ~570 million years ago
   - Moving into the five-vesicle stage, it subdivides:

a. Myelencephalon
   - Develops into the medulla oblongata
     - Responsible for unconscious functions such as breathing and changes in heart rate and blood pressure
     - Can detect toxins in blood from diet and trigger vomiting



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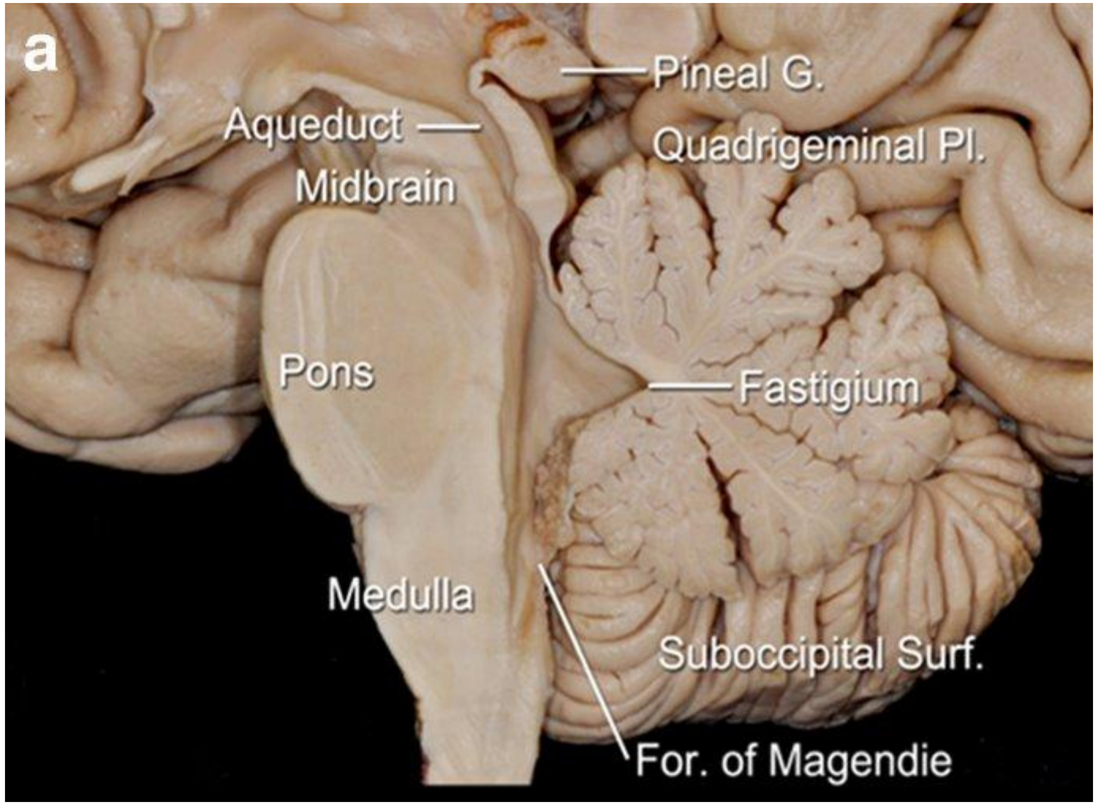
Brain Structures throughout Development

b. Metencephalon

- Develops into the pons and cerebellum
  - Pons
    - Also helps perform involuntary functions like breathing
    - Contains areas that help us hear sounds and taste foods
  - Cerebellum
    - "little brain"
    - Best known for motor control functions (balance, coordination, posture, and learning physical actions)



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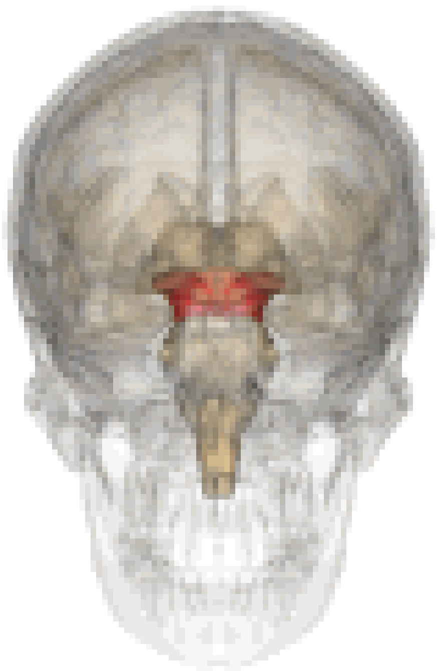
Brain Structures throughout Development

2. Mesencephalon (midbrain)

- Little change from three- to five-vesicle stage
- Many structures with a wide variety of functions
  - Ex. Periaqueductal gray - respond to painful stimuli
  - Ex. Red nucleus and substantia nigra - coordinate complex movements
  - Ex. Tectum - respond to incoming visual stimuli
  - Ex. Ventral tegmental area - processing of reward and motivation



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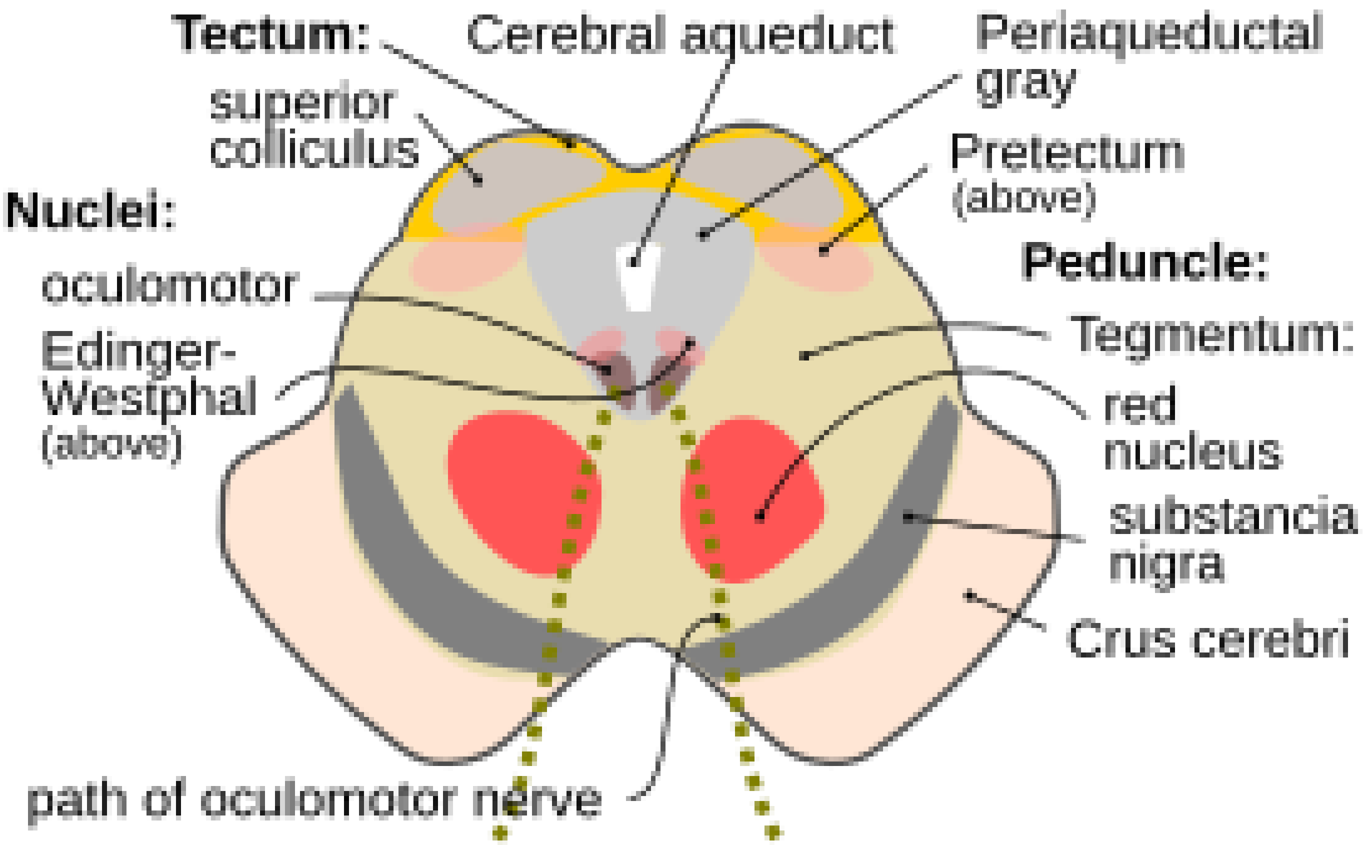
Midbrain Image



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Brain Structures throughout Development

3. Prosencephalon (forebrain)

- Develops into "higher order" brain regions including cerebral cortex
- Largely what you see when you look at brain from side or top
- Subdivided in five-vesicle stage
  a) Diencephalon
     - Contains thalamus ("relay station") and hypothalamus (serves as communication route to endocrine system)
  b) Telencephalon
     - Contains basal ganglia (structures used for motor and habit learning, emotional processing, & action selection) & cerebral cortex (outermost layer of brain; processes behaviors such as attention, memory, & language)
       - Cortex ("bark")

Brain Structures throughout Development

- Consider organization in phylogenetic "timeline"
  - Posterior to anterior
    - Hindbrain (brain stem) - basic survival (respiration & locomotion)
    - Midbrain - motivation & coordinated movements
    - Forebrain – higher order functions such as personality, intentional inhibition of actions, and planning long-term actions
- All structures work together simultaneously to produce range of animal activities

Major lobes of the cortex

- Cortex (bumpy outer surface)
  - Raised ridges (singular: gyrus; plural: gyri)
  - Grooved indentations (singular: sulcus; plural: sulci; sometimes called fissure)
  - Named by function or location

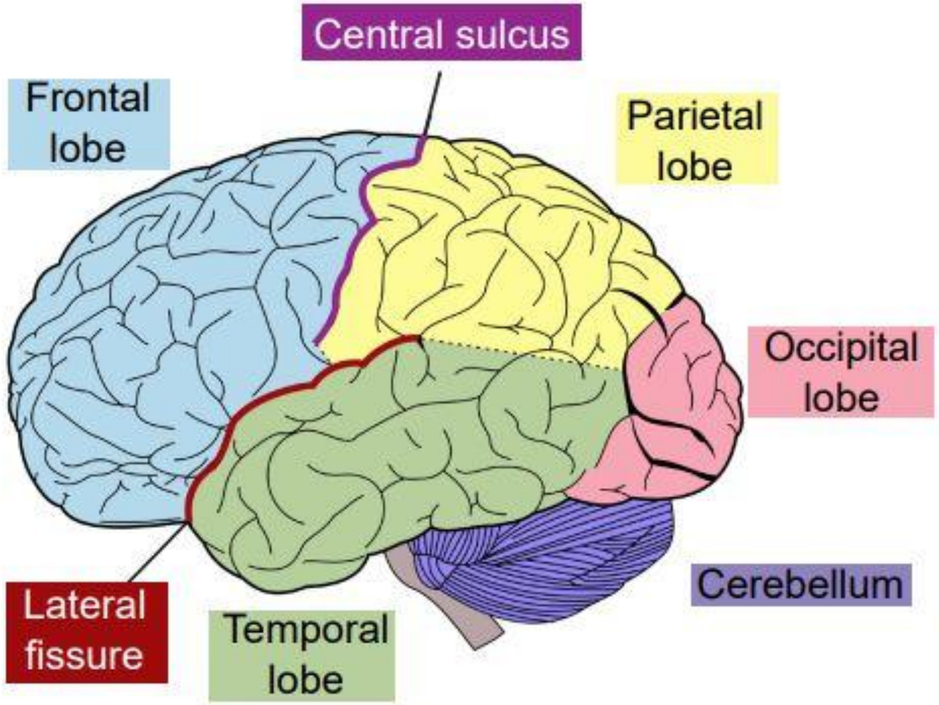
Key Sulci / Fissures

- 3 sulci to learn now:
  - Longitudinal fissure (divides hemispheres; runs along anterior-posterior axis)

https://commons.wikimedia.org/wiki/File:Brain_autopsy_top_view.jpg

Key Sulci / Fissures

- Central sulcus (starts at dorsal part of brain about halfway on anterior-posterior
axis; runs ventrally)
- Lateral fissure (along the anterior and
posterior direction; curves gently dorsally; middle third of the brain in a sagittal view)



Major lobes of the cortex

1. Occipital lobe
2. Temporal lobe
3. Parietal lobe
4. Frontal lobe

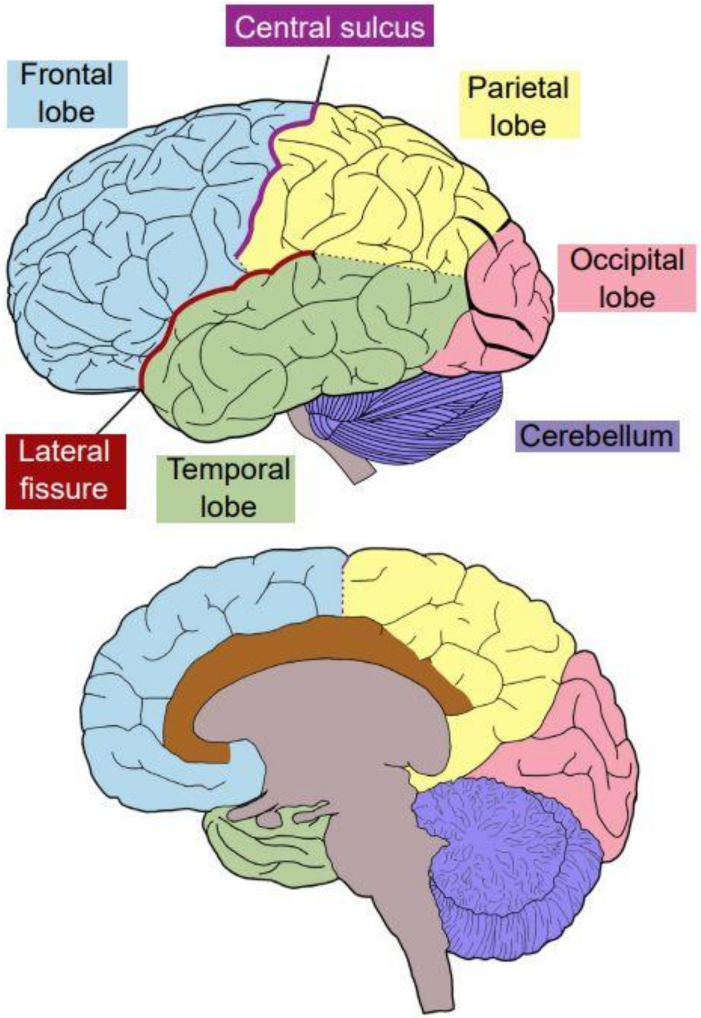


Figure 2.7 Lobes of the telencephalon and two of the major sulci from a lateral view (top) and a midsagittal view (bottom). The insular cortex is not visible from the outside.

Occipital lobe

- Posterior-most section of brain
- No obvious border anatomically
- Smallest lobe
- Main function: processing visual stimuli
- Primary visual cortex (V1) interprets light signals into a representation of visual world
- Other vision-related stimuli are also processed in occipital lobe (motion, orientation, and colour)

Temporal lobe

- Ventral-most lobe
- Lateral fissure marks dorsal border
- Anterior to occipital lobe
- Immediately behind the temple
- Name comes from Latin word meaning time (often, gray hairs first appear at temples)
- Primary auditory cortex (A1) allows interpretation of sound waves
- Hippocampus is buried medially and ventrally in temporal lobe; allows memory-related processes
- Temporal lobe also houses structures important for language (comprehension & production)

Parietal lobe

- In dorsal aspect
- Immediately anterior to occipital lobe and superior to temporal lobe
- One of major functions: sensation of different tactile properties of word around us (touch, temperature, pain, vibration, and other modalities)
- Also responsible for proprioception (ability to identify where parts of body are located)
- Primary somatosensory cortex (S1) (*soma* = body)

Frontal lobe

- Anterior-most part of brain
- Posterior border is lateral sulcus
- Largest of four lobes for mammals
- Contains primary motor cortex (M1) - directly anterior to central sulcus; controls movement of body
- "Higher order" functions (ex. Personality)
  - Mental math
  - Hold string of letters in mind and repeat backward
  - Suppress unacceptable actions (inhibition)

Clinical connection: Phineas Gage

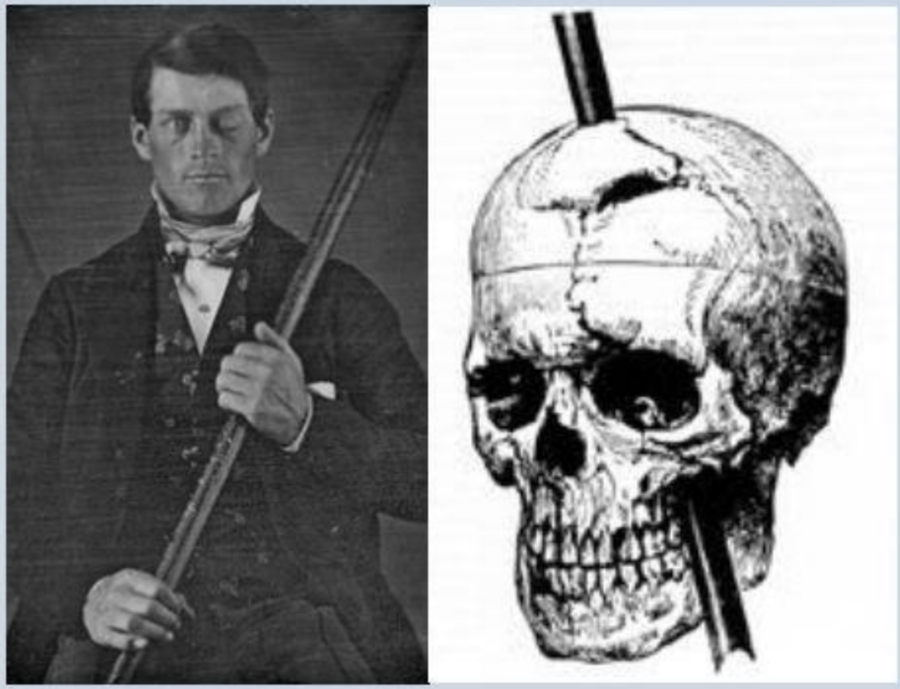
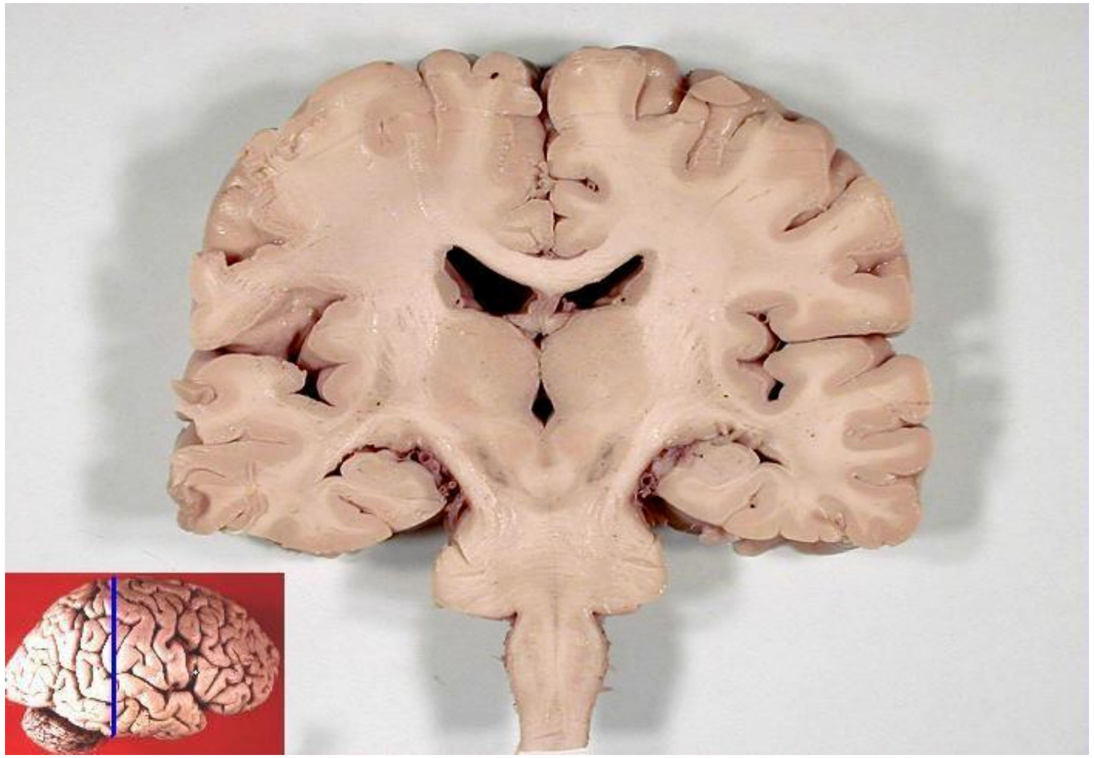


Figure 2.8 Phineas Gage with the tamping rod (left) and a drawing of the injury (right).

Compare / Contrast

Coronal slice of brain



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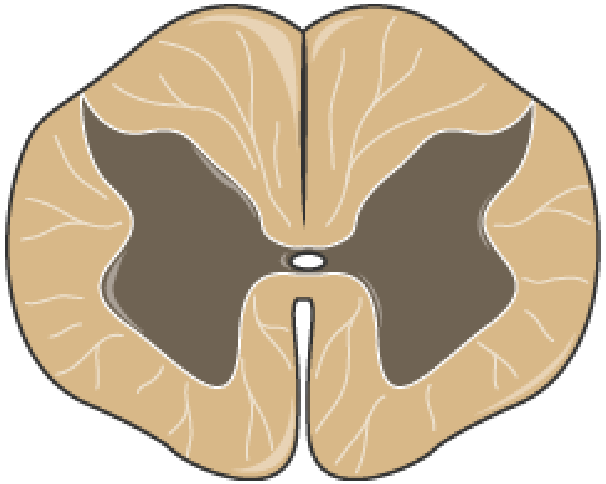
Cross-section of spinal cord



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Spinal cord

- Posterior from brainstem
- Carries information upward to brain & downwards to body's organs and muscles
- Can process sensations and form appropriate motor response without brain input
- Originates at about level of neck and runs to small of back (~44 cm; 17.5 inches)
- Diameter is not uniform (~6.5 mm, or 0.25 inches, to ~13 mm, or 0.5 inches)
- Housed within vertebral column
- Cord is continuous, but overlying vertebrae are divided by sections and numbered
- Branching off from each section of spinal cord are 2 pairs of nerves
    - Afferent (incoming to CNS) branch from dorsal side
    - Efferent (outgoing from CNS) branch from ventral side
- Branches meet and extend away from spinal cord
- After merging = spinal nerves
- 31 pairs of spinal nerves in humans

Spinal cord: Human walk upright!

- Notice change in our walking posture affects use
  of anatomical language as we move from the brain to the spinal cord

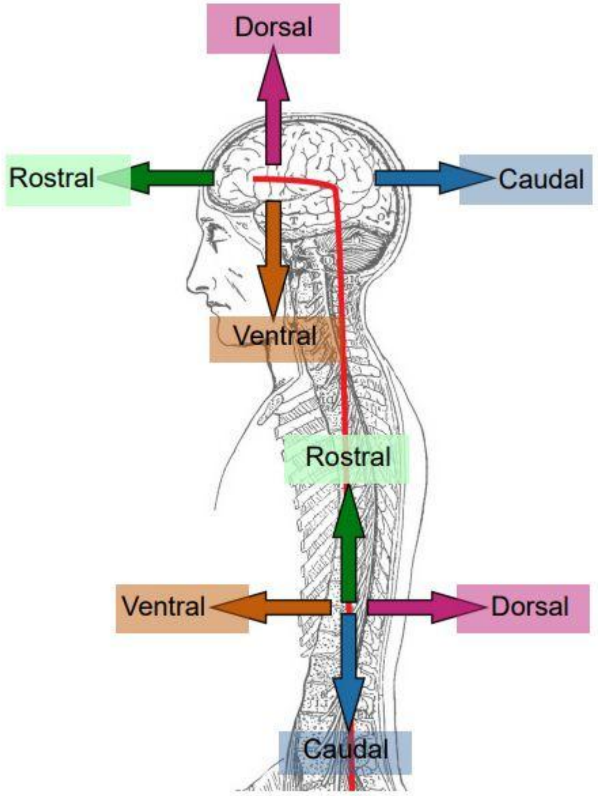


Figure 2.9 Unlike other mammals like dogs or cats, humans walk upright, giving us a "hooked" nervous system.

Spinal cord: Sections

- Cervical
- Thoracic
- Lumbar
- Sacral

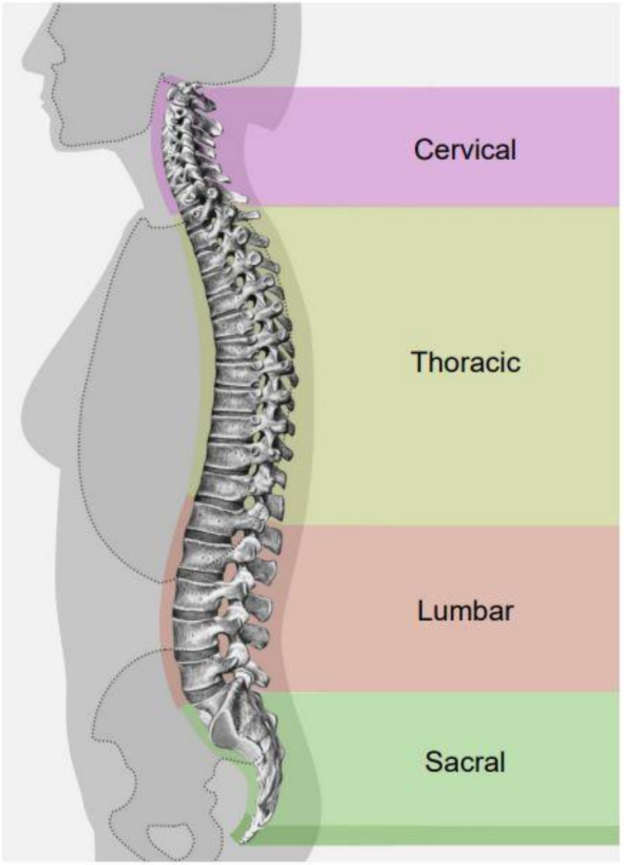


Figure 2.10 The names of the regions of the vertebral column, the bones that protect the spinal cord.

Spinal cord: Cervical

- Anterior-most section
- 8 pairs of spinal nerves
- Innervate muscles in neck, shoulders, arms, & hands
- Afferent nerves detect somatosensory inputs from same areas
- C3-C5 innervate diaphragm – injury at this level or higher can be fatal
- Widest diameter of spinal cord - corresponding to many inputs and outputs to arms

Spinal cord: Thoracic

- 12 pairs of spinal nerves
- Innervate middle trunk area, intercostal muscles between ribs, & abdominal muscles
- Some branches are responsible for changing activity of various internal organs during flight-of-flight response (autonomic nervous system)

Spinal cord: Lumbar

- 5 pairs of spinal nerves
- Carry motor commands to hips, highs, & knees
- Afferent lumbar inputs detect sensory information from ventral sides of legs
- Swelling that increases diameter compared to thoracic or sacral areas

Spinal cord: Sacral

- Posterior-most section
- 5 pairs of nerves
- Control flexing of toes
- Detect sensory information around genital organs & dorsal aspects of legs
- Parasympathetic nerves come from this region - innervate colon, bladder, and genital organs

Spinal cord

- More anterior injuries result in more affected body parts
- US President Franklin Delano Roosevelt likely damaged posterior spinal cord structures - lost function of legs
- Actor Christopher Reeves injured spinal cord at anterior most level of C1 – complete paralysis and lack of sensation from neck down

Spinal cord

- Cut in transverse plane
- Results are cross-sections
- Similarities in cross-sections
  - Butterfly-shaped structure of gray matter (cell bodies)
  - Surrounded by white matter (communication pathways)
  - Ascending sensory tracts & descending motor tracts run along outer portions of spinal cord section
  - Somatosensory information arrives into spinal cord from dorsal side
  - Cell bodies of most sensory neurons are close to dorsal side = dorsal root ganglion
  - Efferent motor nerves exit spinal cord on ventral side

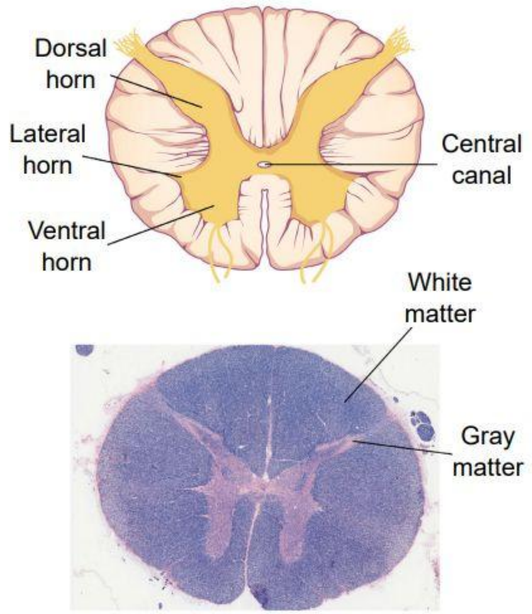


Figure 2.12 Cross-section (transverse) of the spinal cord showing a few anatomical features (top). Section of spinal cord stained with LFB, which dyes myelin in blue, which is why white matter looks more blue than gray matter (bottom).

Spinal cord

- Ratio of white to gray matter differs across sections of spinal cord
- In general, more white matter at anterior regions of spinal cord compared to poster parts
- CNS ends at spinal nerves

Peripheral nervous system (PNS)

- Intermediary between CNS and rest of body
- Two other pairs of anatomical terms are required to discuss location and direction within the PNS:
    1) proximal and distal
    2) contralateral and ipsilateral
- Divided into 3 main branches:
    1) Somatic nervous system
    2) Autonomic nervous system
    3) Enteric nervous system

Anatomical terms

- Proximal - close in proximity to CNS
- Distal - more distant from CNS
- Contralateral - on opposite sides
- Ipsilateral – on the same side

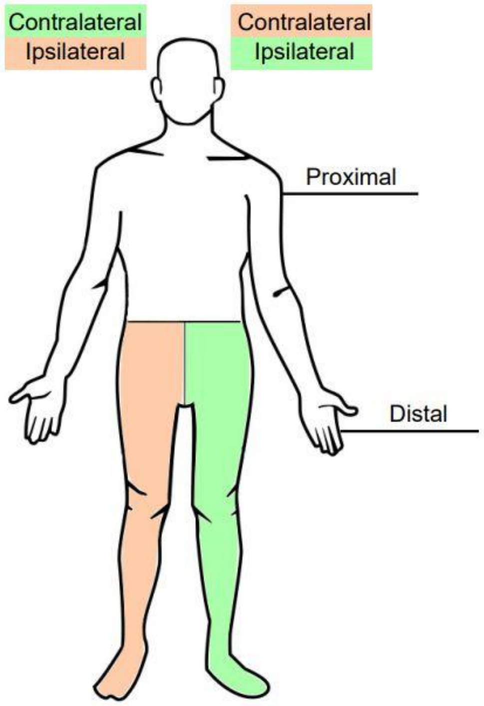


Figure 2.14 Anatomical language used in describing relationships from parts of the nervous system.

PNS: Somatic nervous system

- All parts of PNS involved with outside environment (sensing or acting on it)
- AKA voluntary nervous system since it is used to cause muscle movement that is intentional

PNS: Autonomic nervous system

- Parts of PNS that deal with internal environment (detecting internal state and influencing internal organs)
- Unconscious and without intentional control
- Has two branches (sympathetic and parasympathetic nervous systems) which are always sending signals and influencing internal organs

PNS: Autonomic nervous system

- Sympathetic nervous system – activated when we are facing real or perceived threats
  - Responsible for fight-or-flight response (increased heart rate, quickened breathing, body temperature can increase; pupil dilate, bronchioles dilate, & liver and kidneys activate a variety of enzymes)
  - Nerves branch off spinal cord at thoracic and lumbar levels (thoracolumbar)
  - Clumps of cells run alongside the spinal cord = sympathetic ganglion
- Parasympathetic nervous system
  - Response for rest-and-digest response (relaxed, satisfied, and sluggish)
  - Originates predominantly from the cervical level but some sacral areas are involved
  - Receives signals from several cranial nerves
  - Additional info: CN X, the vagus nerve, innervates many organs in midsection of body (vagus comes from same root word as vagrant - wanders around body)

Innervation of Sympathetic & Parasympathetic Nervous Systems

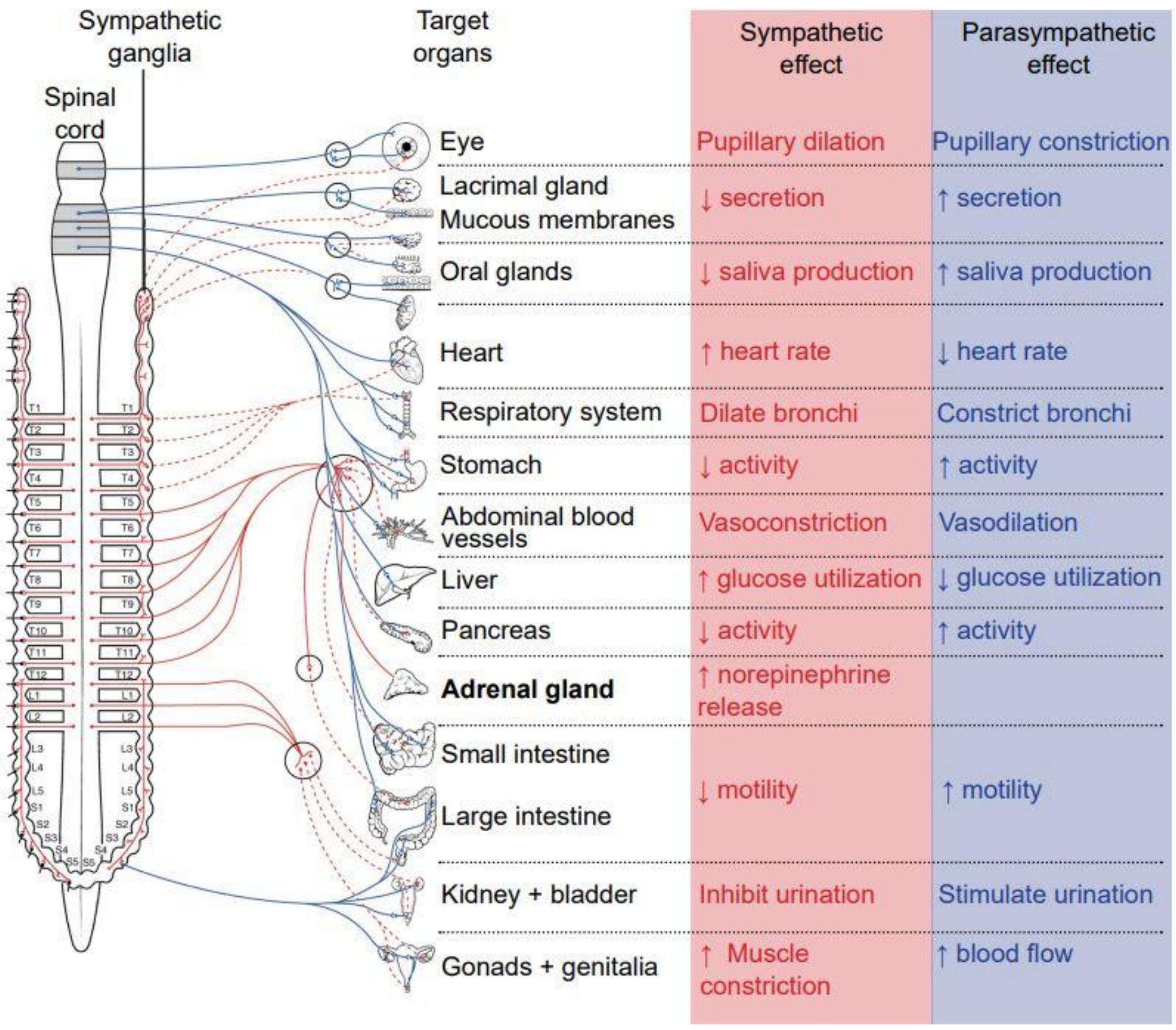


Figure 2.15 Diagram showing innervation of different organs by the sympathetic and parasympathetic nervous systems and the corresponding effect. Note that the adrenal gland does not have parasympathetic activity.

PNS: Enteric nervous system

- Dense mesh of neurons (half a billion) surrounding digestive tract (including esophagus, stomach, and intestines)
- Receives information from sympathetic and parasympathetic nervous systems, and functions without our conscious knowledge
- Not part of autonomic nervous system as these responses do not share the same reflex pathway and can work independently of vagus nerve

Cranial nerves

- 12 pairs
- Can control motor functions, general or specialized sensory functions, or both

Cranial Nerve	Function	Description
CN I Olfactory nerve	Sensory	Sense of smell
CN II Optic nerve	Sensory	Sense of vision
CN III Oculomotor nerve	Motor	Control of extraocular muscles which allow movement of eyeballs; constriction of pupils; changing of lens shape
CN IV Trochlear nerve	Motor	Control of the superior oblique muscle of the eye that moves the eyeball down and lateral
CN V Trigeminal nerve	Sensory + motor	Tactile and pain sensory information from the face and mouth; Control of muscles used in chewing
CN VI Abducens nerve	Motor	Control of the lateral rectus muscle of the eye that moves the eyeball outward laterally
CN VII Facial nerve	Sensory + motor	Control of the muscles that allow for facial expressions; Taste sensation on the anterior 2/3rds of the tongue
CN VIII Vestibulocochlear nerve	Sensory	Detection of sound information and head positional (vestibular) information
CN IX Glossopharyngeal nerve	Sensory + motor	Detection of somatic sensory in the middle ear and posterior 1/3rd of the tongue; Taste sensation on the posterior 1/3rd of the tongue; Controls the stylo-pharyngeal muscle that allows swallowing
CN X Vagus nerve	Sensory + motor	Control of the internal organs by autonomic nervous system using parasympathetic activity
CN XI Accessory nerve	Motor	Control of the sternocleidomastoid and trapezius muscles of the neck and shoulders
CN XII Hypoglossal nerve	Motor	Control of the muscles of the tongue

Table 2.16 The twelve cranial nerves and their function.

Questions about Cranial Nerves

What questions might we ask about the cranial nerves

Support structures of the nervous system: Brain circulation & cerebral blood flow

- Brain has high demand for oxygen and nutrients (2% of body weight, but 15% of total cardiac output)
- Oxygenated blood moves into brain via paired vertebral arteries and internal carotid arteries
- Left and right vertebral arteries merge to form single basilar artery
- Basilar artery and internal carotid arteries form circle of Willis

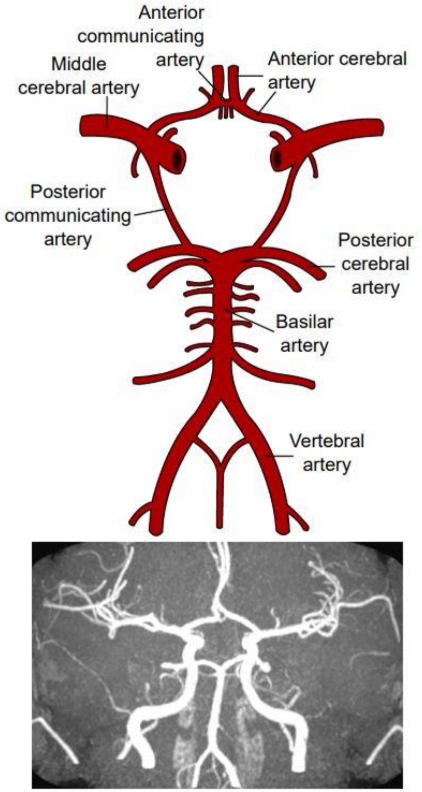


Figure 2.17 Diagram of the circle of Willis (top) and an angiogram (bottom) showing the structure in real life.

For more information: [Circle of Willis – 3D Anatomy Tutorial]

Brain circulation & cerebral blood flow

- Circle of Willis has paired "exit" arteries that distribute blood to other areas of brain
- Anterior cerebral arteries = provide to dorsomedial cortical structures and deep brain structures
- Posterior cerebral arteries provide to occipital lobe
- Middle cerebral arteries branch off internal carotid artery and provide to lateral cortices

For more information: [Circle of Willis – 3D Anatomy Tutorial]()

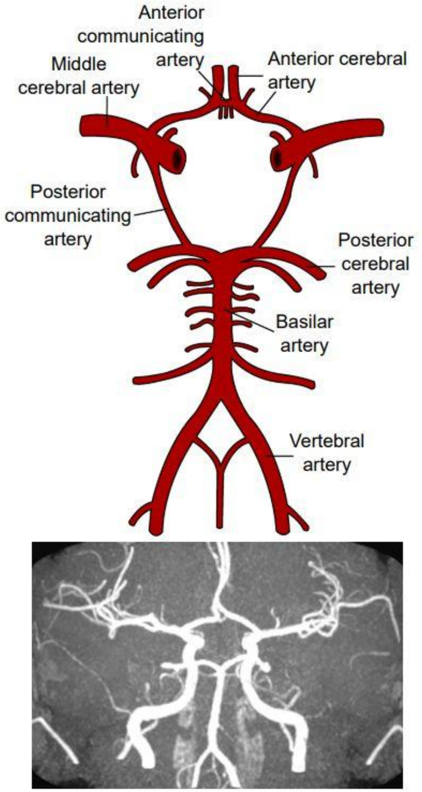


Figure 2.17 Diagram of the circle of Willis (top) and an angiogram (bottom) showing the structure in real life.

Clinical connection: Stroke

- Common & life-threatening
- Loss of blood flow
- 2nd highest cause of death in world (WHO, 2016)
- #1 risk factor = high blood pressure
- Two types: ischemic (80%) and hemorrhagic (20%)
- Hemorrhagic is less common but more deadly than ischemic
- Determine / diagnose area based on presentation of symptoms
- Treatments differ ("clot-busting" drug for ischemic)

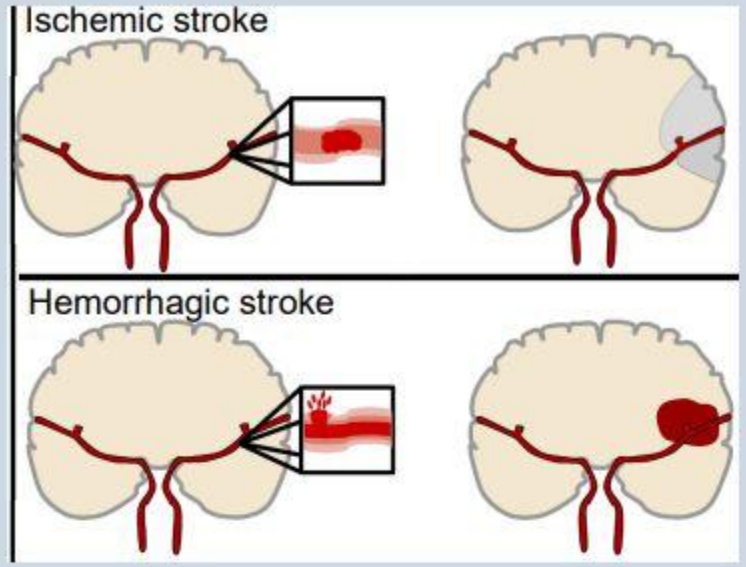


Figure 2.18 Diagram illustrating the two main types of stroke and the effect on blood flow to the brain

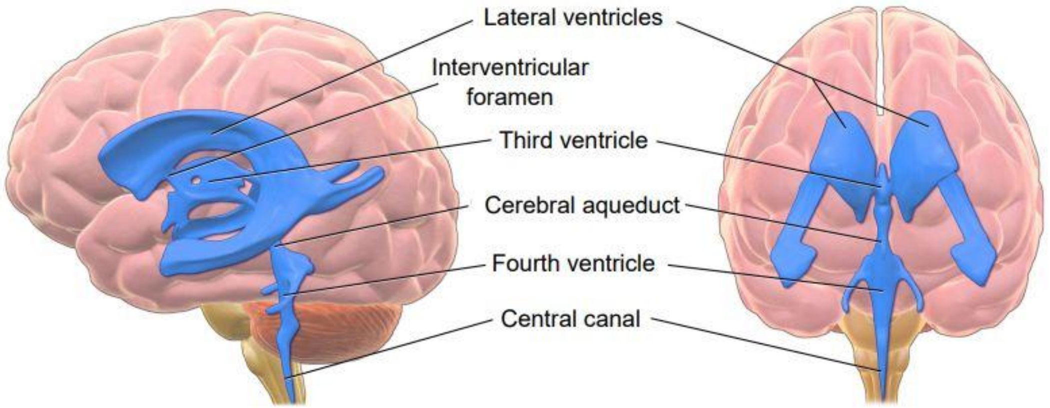
Blood brain barrier (BBB)

- Important for oxygen and nutrients to pass from blood to brain tissue
- Anatomical adaptation that selectively transports substances necessary to normal biological function while excluding potentially harmful invaders
- BBB surrounds blood vessels in brain
- Made of endothelial cells and astrocytes (a type of glial cell)
- BBB is injured in all variety of medical disorders
- Unknown what role disruption of BBB has in brain disorders
- Exclusive nature of BBB is double-edged sword (difficult to deliver drugs to brain)

Ventricles & Cerebrospinal fluid (CSF)

- Ventricles = spaces near the medial aspect of the brain
- 4 in total
  - o 2 lateral ventricles
  - o third ventricle
  - o fourth ventricle
- Ventricles are filled with cerebrospinal fluid (CSF)
- CSF is high salt water solution
- Osmolarity of CSF allows buoyancy and brain to remain "floating" in skull

Figure 2.20 The ventricular system consists of several interconnected chambers filled with cerebrospinal fluid (CSF).



Cerebrospinal fluid (CSF) continued

- Also found in meninges (80% of CSF exists in this space) forming cushioning
- Still, movement that is too abrupt can cause traumatic brain injury
- CSF can wash impurities out of brain
- Typical volume = ~150 mLs (<½ cup)
- Frequent turnover of CSF so it gets absorbed back into body regularly
  - o Each daily, body produce ~0.5 L of CSF so there are a few cycles daily
- Cellular waste materials from neurons can get dissolved & degraded outside of brain

Clinical connection: Hydrocephalus

- 1 in 200 newborns and a small number of adults are affected
- Historically called "water on the brain"
- CSF volume increases
- Intracranial pressure is elevated
  - Fever, stiff neck, headache, seizures, altered mental status
- Children may exhibit bulging parts on skull and expansion of forehead
- Clearance of CSF may fail while production remains normal OR entrance into central canal may be narrowed or blocked
- Typical treatment: implant shunt surgically

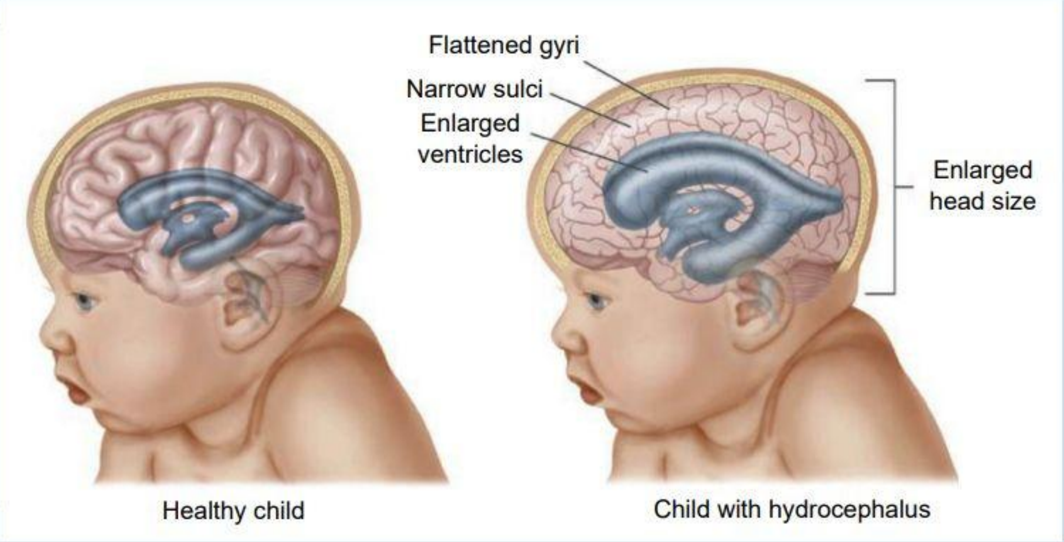
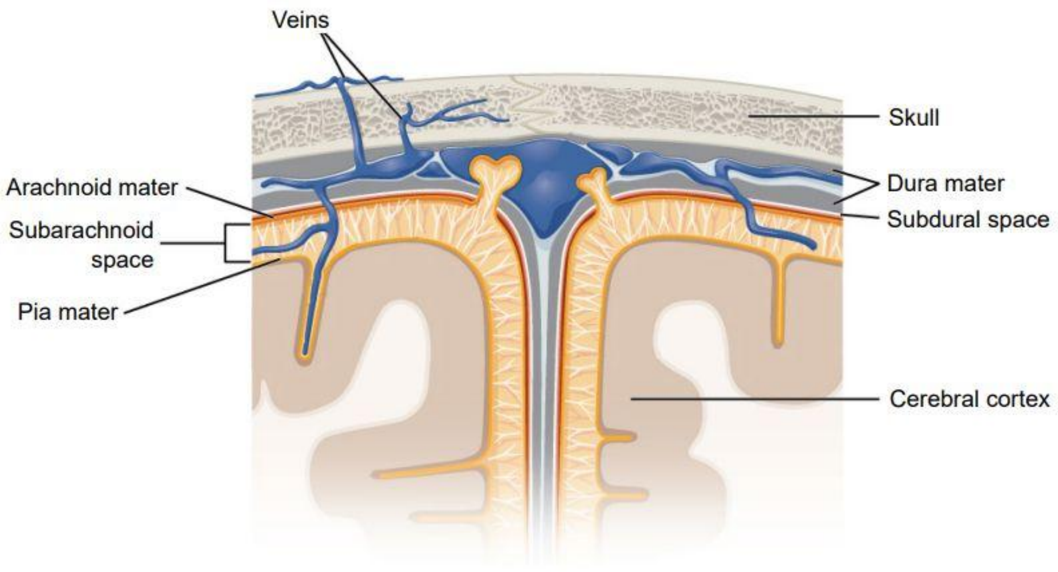


Figure 2.21 Hydrocephalus is one of the most common birth defects, affecting around 0.1% of births in the United States. It can also affect adults. Hydrocephalus can be deadly.

Meninges

- Protective buffer separating soft brain from rigid bone
- Series of protective membranes
    1. Dura mater
    2. Arachnoid mater
    3. Pia mater
- Organic "bubble wrap" that encases a fragile nervous system

Figure 2.22 The meninges are a series of protective membranes that surround the CNS.



Meninges Layers

1. Dura mater
   - Thick, fibrous material (up to 0.8 mm thick in adult)
   - Attached to inside of skull with highly resilient connections found at sutures between cranial plates
   - Name originates from Latin for tough mother
2. Arachnoid mater
   - Middle layer
   - Delicate fibers that resemble spider web (where name comes from)
   - Protrusions allow for CSF to drain into sinuses (CSF exists underneath this layer in the subarachnoid space)
3. Pia mater
   - Very fragile
   - In direct contact with surface of brain, following sulci and gyri
   - Name means pious mother

Clinical connection: Meningitis

- Inflammation of the meninges
- Potentially deadly
- Exposure to infection (viruses or bacteria like *Neisseria meningitidis*) is a common cause
  - These infectious agents are highly transmissible in close contact, but vaccinations are highly effective & broad-spectrum antibiotics are effective
- Brain gets compressed from all sides (increasing intracranial pressure and resulting in same symptoms as noted in hydrocephalus)

Meningococcal B Vaccine in Nova Scotia

- https://novascotia.ca/meningococcal-vaccines/
  - 2 vaccinations
    - Meningitis A
    - Meningitis B
  - Living in quarters
  - Clinic

Potentially Helpful Websites

- Neurosynth.org
- BrainFacts.org